

STRATEGIC HIGH ALTITUDE INFRARED BACKGROUNDS

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13 ABSTRACT (Maximum 200 words) This work describes the work done during the first year of a contract to analyze and model data from high altitude background measurements. The contract has 5 separate tasks: 1. MSX Data Analysis: 2.1 Trace Species in Modtran, 2.2 Radiance Inversion Techniques, 2.3 Mesospheric Radiance Model, 2.4 FAScode for the Environment (FASE). In Task 1, techniques for analyzing data from the Midcourse Space Experiment (MSX) are developed, including developing experiment plans, developing software for the automated analysis of data from visible and ultraviolet imagers, and developing techniques for correlating data from meteorological satellites with MSX data. In Task 2.2, a package for the general inversion for advanced retrieval of atmospheric species from high spectral resolution measurements is described. In Task 2.4, progress in the development of the line-by-line atmospheric transmittance/radiance program FASE (FAScode for the Enviroment) is described.				
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1. Introduction

This report summarizes the work done in the first year of the contract "Strategic High Altitude Infrared Backgrounds: Data Reduction, Applications and Modeling", Contract No. F19628-93-C-0040. As stated in the Phillips Lab PRDA, the goal of this contract is to "...provide models and codes to predict infrared background phenomenon to be encountered by advanced space based systems operating in natural and disturbed backgrounds." To accomplish this goal, the contract has been divided into five tasks:

1. MSX Data Analysis
 - 2.1 Trace Species in Modtran
 - 2.2 Radiance Inversion Techniques
 - 2.3 Mesospheric Radiance Model
 - 2.4 FASCODE for the Environment (FASE)

We will report here on each task separately.

2. MSX Data Analysis

The Midcourse Space Experiment (MSX) is a satellite designed to measure the backgrounds against which space-based strategic surveillance systems must operate. It contains a variety of sensors, both imagers and spectrometers, operating from the longwave infrared to the ultraviolet. A good reference to the MSX program is given in:

Mill, J. D., R.R. O'Neil, S. Price, G.J. Romick, O.M Uy, E.M. Gasposchkin, G.C. Light, W.W. Moore, Jr., T. L. Murdock, A.T. Stair, "The Midcourse Space Experiment: An Introduction to Spacecraft, Instruments and Scientific Objectives", *Journal of Spacecraft and Rockets*, Vol. 31, No. 5, September-October 1994

AER's responsibility in the MSX program is to provide for the analysis of data both from MSX and from other sources complimentary to MSX. AER's work is an extension of the work performed on a previous contract: "Development of Remote Sensing Algorithms for Atmospheric Variables from Radiometer Data-Phase II", Contract No F19628-91-C-0167.¹ In this the prelaunch phase, we are working on the following tasks:

1. Development of MSX experiment plans
2. Development of software to perform automated analysis of the MSX UVISI and SBV data.
3. Analysis of radiance data from the TIROS Operational Vertical Sounder (TOVS) instrument from the NOAA Polar Orbiting satellites.

¹ Gallery, W. O., J.-L. Moncet, 1994, "Development of Remote Sensing Algorithms for Atmospheric Path Variability From Radiometer Data", PL-TR-94-2263

In addition, we performed a study along with Al Zachor of ARC, Inc. on the possibility of detecting nitric acid with the sensors on MSX. The results of this study, a paper entitled "Feasibility of the Remote Detection of Fuming Nitric Acid by MSX", is included as Appendix A.

2.1 MSX Experiment plans

These plans set out the experiment objectives and specify the modes of operation of both the spacecraft and the individual instruments. AER has the principal responsibility for the following MSX experiment plans:

ELE-4: Airglow Staircase Survey

ELE-10: Vertical Profile Survey

ELE-19: Stratospheric Trace Gas Survey

These plans were originally developed under the contract mentioned previously. They have been revised under this contract to reflect changes in the MSX instrument characteristics and the nominal experiment duration. However, since it is likely that these plans will be revised further, we will not include them here.

2.2 SBVISI: UVISI and SBV Automated Analysis Software

Under the current plans, the data from each experiment will first be run through a set of automated analysis programs. These programs will reduce the data into a set of images, profiles and indicators designed to let the researcher make a quick overview of the data and decide whether there are any significant or unusual phenomena which should be analyzed further.

AER has the responsibility for creating the automated analysis software for the UVISI and SBV instruments. The UVISI and SBV instruments on MSX are a set of visible and ultraviolet imagers designed to compliment the infrared instruments. The automated analysis programs for these instruments (collectively known as SBVISI) are designed to do the following:

1. Create a time series of images tagged in time and geolocated in object space (lat/lon/altitude of tangent points along various lines-of-sight) which can be compared with the images from the SPIRIT III instrument.
2. From these images, extract vertical radiance profiles coregistered with coincident SPIRIT III radiance profiles.
3. Ratio the measured SBVISI profiles with standard or nominal profiles to create indicators of significant or unusual events.

Version 1 of the SBVISI Automated Analysis Software was completed and delivered. Currently it lacks an interface to the geolocation software MAMBA, which is being developed by another contractor (Radex, Inc.) As soon as the interface is available, it will be integrated into the SBVISI software.

A partial draft report describing the functions and usage of the SBVISI software has been written. Since this document also acts as the Interface Control Document (ICD) for the software, the draft was also provided to the automated analysis team at the Phillips Lab so that they could

begin to integrate the SBVISI software into the overall automated analysis activity. A copy of this document entitled "SBVISI: Automated Processing Software For the UVISI and SBV Data at the Earthlimb DAC" is attached as Appendix B.

3. Trace Species in Modtran

This task involves including the absorption of certain trace gases into the computer program MODTRAN. Soon after the start of this contract, it was learned that another contractor, Spectral Sciences Inc. of Burlington, Massachusetts, had already performed this task. Therefore no work was performed on this task and it is considered closed.

4. Radiance Inversion Techniques

The work on this task is described in a presentation entitled "A General Inversion Package for Advanced Retrieval of Atmospheric Species from High Spectral Resolution Measurements" which was delivered at the Annual Review Conference on Transmission Models, Phillips Laboratory, Hanscom AFB, MA, June 7-8, 1994. A copy of this presentation is attached as Appendix C.

5. Mesospheric Radiance Model

No funds were allocated for this task for this year and no work was performed.

6. FASCODE for the Environment (FASE)

Work on this task is described in the presentation "FASCODE Environment (FASE), " which was delivered at the Annual Review Conference on Transmission Models, Phillips Laboratory, Hanscom AFB, MA, June 7-8, 1994. A copy of this presentation is attached as Appendix D.

Appendix A: Feasibility of the Remote Detection of Fuming Nitric Acid by MSX

Feasibility of the Remote Detection of Fuming Nitric Acid by MSX

William Gallery

Malcom Ko

AER, Inc.

Al Zachor

ARC, Inc.

April 14, 1994

1. Introduction

We have been asked to perform a quick study of the feasibility of detecting fuming nitric acid with the sensors on MSX. The problem states that there would be a "large" release of "fuming nitric acid". We have decided to approach the problem by asking the question: What is the smallest release that could be detected from MSX?

2. Chemistry of Fuming Nitric Acid

Fuming nitric acid is a commonly used oxidizer for rocket fuels. According to Clark¹, fuming nitric acid is a mixture of nitric acid (HNO₃) and dissolved nitrogen tetroxide (N₂O₄), usually with 0.6 percent of hydrogen fluoride (HF) to prevent corrosion of the fuel tank. In the US there are four standard mixtures corresponding to 0, 7, 14 and 21 percent N₂O₄. The most commonly used is Type III (14 percent) and is referred to as IRFNA--Inhibited Red Fuming Nitric Acid. In the Soviet Union, there are two rocket grades²: 20 percent and 28 percent N₂O₄. The Scud missile uses IRNRA, presumably the 20 percent mixture.

(However, according to the Aldrich chemical catalog³, "nitric acid, red fuming" contains "dissolved oxides 5-10 percent as N₂O₃".)

Upon release into the atmosphere, N₂O₄ will convert thermally to NO₂. The equilibrium between the two is governed by the equation⁴:

$$[\text{NO}_2][\text{NO}_2]/[\text{N}_2\text{O}_4] = k_{\text{equ}}(T) \quad 1$$

where:

$$k_{\text{equ}}(T) = 5.9 \times 10^{-29} \exp(6600/T) \quad 2$$

In addition, both NO₂ and N₂O₄ undergo photo-disassociation in sunlight. These reactions are described in reference⁵. Basically, NO₂ converts to HNO₃ and to NO which rapidly converts back to NO₂. N₂O₄ converts to NO₂. HNO₃ rains out of the troposphere where it has a lifetime of weeks.

¹ Clark, J. D. IGNITION! An Informal History Of Liquid Rocket Propellants, Rutgers U. Press, New Brunswick, New Jersey, 1972, page 62.

² Op cit, page 118

³ Aldrich Chemical Company, Chemical Catalog of Fine Chemicals, Milwaukee, 1990, page 956

⁴ NASA, 1992, Chemical Kinetics and Photochemical Data for Use in Stratospheric Modeling, Evaluation Number 10, JPL Publication 92-20, page 98.

⁵ Wayne, R. P., 1991, Chemistry of Atmospheres, Second Edition, Oxford U. Press, New York, chapter 5.

3. Spectral Signatures

Table 1 lists the absorption bands of HNO_3 , NO_2 , and N_2O_4 within the bandpasses of channels 5 (740 to 950 cm^{-1}) and 2 (1960 to 4000 cm^{-1}). Line parameters for the bands of HNO_3 and NO_2 are available on the HITRAN Database⁶. In addition, these bands are included in MODTRAN⁷. Although the bands of N_2O_4 have been measured^{8,9}, so far we have been unable to find any measured cross-sections suitable for quantitative calculations. However, we will continue to research the question.

Table 1. Absorption Bands Of HNO_3 , NO_2 , And N_2O_4 Within The Bandpasses Of MSX Channels 5 (740 to 950 cm^{-1}) and 2 (1960 to 4000 cm^{-1} .)

Molecule	Center Frequency (cm^{-1})	Band Strength ($\text{cm}^{-1}/(\text{molec cm}^{-2})$)
HNO_3	763.15	1.24×10^{-18}
	877.	1.22×10^{-18}
	879.12	1.26×10^{-17}
	885.	2.03×10^{-18}
	896.45	9.84×10^{-18}
NO_2	749.65	5.44×10^{-19}
	2805.52	3.33×10^{-22}
	2898.19	1.06×10^{-19}
	2906.07	2.88×10^{-18}
N_2O_4	750	
	2618	
	2962	
	3120	
	3442	

⁶ Rothman, L. S., 1992, HITRAN 1992, Phillips Lab (see also JQSRT, **48**, no. 5&6, Nov/Dec. 1992)

⁷ Berk, A., L. S. Bernstein, and D. C. Rohbertson, 1989, MODTRAN: A Moderate Resolution Model for LOWTRAN 7, GL-TR-89-0122

⁸ A. Gutman, 1962, Absolute Infrared Intensity Measurements on Nitrogen Dioxide and Dinitrogen Tetroxide, *J. Quant. Spectrosc. Radiat. Transfer*, **Vol. 2**, pp.1-15

⁹ Melen, F., Pokorni, and M. Herman, 1992, Vibrational band analysis of N_2O_4 , *Chem. Phys. Lett.*, **Vol 194**, p181-186

4. Simulation of a Large Release

Channel 2 of the SPIRIT III interferometer (2.9-4.9 micrometers, 2000-4000 cm^{-1}) can view down to the nadir without saturating while channel 5 ((10.6-13.0 micrometers, 770-945 cm^{-1}) can view down to a tangent height of about 8 km. (For Channel 5 to be able to view the nadir, its performance would have to be much worse than predicted.) The other 3 channels saturate at altitudes above 20 km. From Table 1, HNO_3 has a spectral signature in channel 5 while NO_2 and N_2O_4 have signatures in channel 2. Therefore two possible detection scenarios present themselves: 1. detection of a cloud of NO_2 and N_2O_4 on the ground, and 2. detection of a cloud of HNO_3 in the atmosphere above 8 km.

4.1 Detection Of A Cloud Of NO_2 And N_2O_4 On The Ground

This scenario assumes that there is an optically thin cloud of NO_2 against a uniform background (only NO_2 is considered here since we have no cross-sections for N_2O_4 .) We used a scaling based on the methodology developed by Zachor¹⁰ to determine the minimum detectable concentration of NO_2 . The conditions are:

Observations/data processing:

SPIRIT III interferometer, channel 2, nadir view

Measurement time = 12.9 sec (coadd three long scans)

Contrast spectrum (target minus background) over 2850-2935 cm^{-1} region
processed by spectral correlation with a FASCODE reference spectrum

Calculated effective total noise radiance = $7 \times 10^{-9} \text{ W/cm}^2 \text{ sr cm}^{-1}$ for channel 2

Detection probability = 95 percent, false detection probability = 1 percent.

Target:

10-meter vertical-thickness cloud at ground level filling the channel-2 FOV

Temperature difference between the cloud and adjacent background = 5 K

Using these parameters, the **minimum detectable concentration of NO_2 is 4600 ppmV** (parts per million by volume).

Notes:

1. With the new beamsplitter coating and end mirrors ordered by O'Neil, the performance would be ten times better, i.e., the minimum detectable concentration would be 460 ppmV.
2. The above minimum detectable concentration is easily scaled with fraction of cloud in the IFOV and with the target-background temperature difference (via the Planck temperature derivative.)

¹⁰ Zachor, A. S, B. Banchi, and M. Ahmadjan, 1971, Detection of trace gases using high-resolution spectroscopy, *SPIE*, Vol. 277, p86-91

The total amount of NO₂ in the cloud can be calculated as follows. The number density n corresponding to this concentration is:

$$n = 2.69 \times 10^{19} \text{ molecules cm}^{-3} \times 4600 \times 10^{-6} = 1.24 \times 10^{17} \text{ molecules cm}^{-3} \quad 3$$

The density ρ is:

$$\rho = n \times 46 \text{ gm/mole} / 6.023 \times 10^{23} \text{ molecules/mole} = 9.5 \times 10^{-6} \text{ gm cm}^{-3} \quad 4$$

The footprint of channel 2 at the ground is 1.7 by 2.5 km for an area A of $4.2 \times 10^{10} \text{ cm}^2$. The depth of the cloud h is 10 meters = $1 \times 10^4 \text{ cm}$. The total mass m is

$$m = \rho \times A \times h = 4 \times 10^9 \text{ gm} = \mathbf{4,000 \text{ metric tons}} \quad 5$$

Note that this mass is the amount that is within the MSX FOV. A denser cloud that does not fill the FOV but has the same mass will produce the same signal, within the assumptions of the technique.

This amount can be reduced by: a. better beamsplitter coating and end mirrors--factor of 10, and b. relaxing the detection probability criterion--factor of 10. Both improvements would bring the minimum detectable mass to 40 metric tons.

This value for the minimum detectable amount is based on a crude scaling of a previous calculation. It is possible that a refined calculation would reduce the amount to a more reasonable level. We propose that this calculation be performed.

4.2 Detection Of A Cloud Of HNO₃ In The Atmosphere

As a first order approach, we will consider the following scenario. HNO₃ is released continuously from a point source on the ground. It diffuses horizontally and vertically until it reaches 10 km. Assume that enough HNO₃ reaches 10 km so that the signature measured by MSX increases 10 percent over the ambient signal. We then work backwards to calculate how much HNO₃ would have to be released to produce this effect. If the amount is unreasonable then we can conclude that this detection scheme is not feasible. Otherwise, the scheme merits further study.

Figure 1 shows a MODTRAN calculation of the transmittance and radiance of the ambient atmosphere for a limb path with a tangent height of 10 km. The radiance is the dashed line, the total transmittance is the dashed-dotted line, and the transmittance due to HNO₃ alone is the solid line. The strong feature at 880 cm^{-1} is due to HNO₃ and there is little contribution from other species in this region.

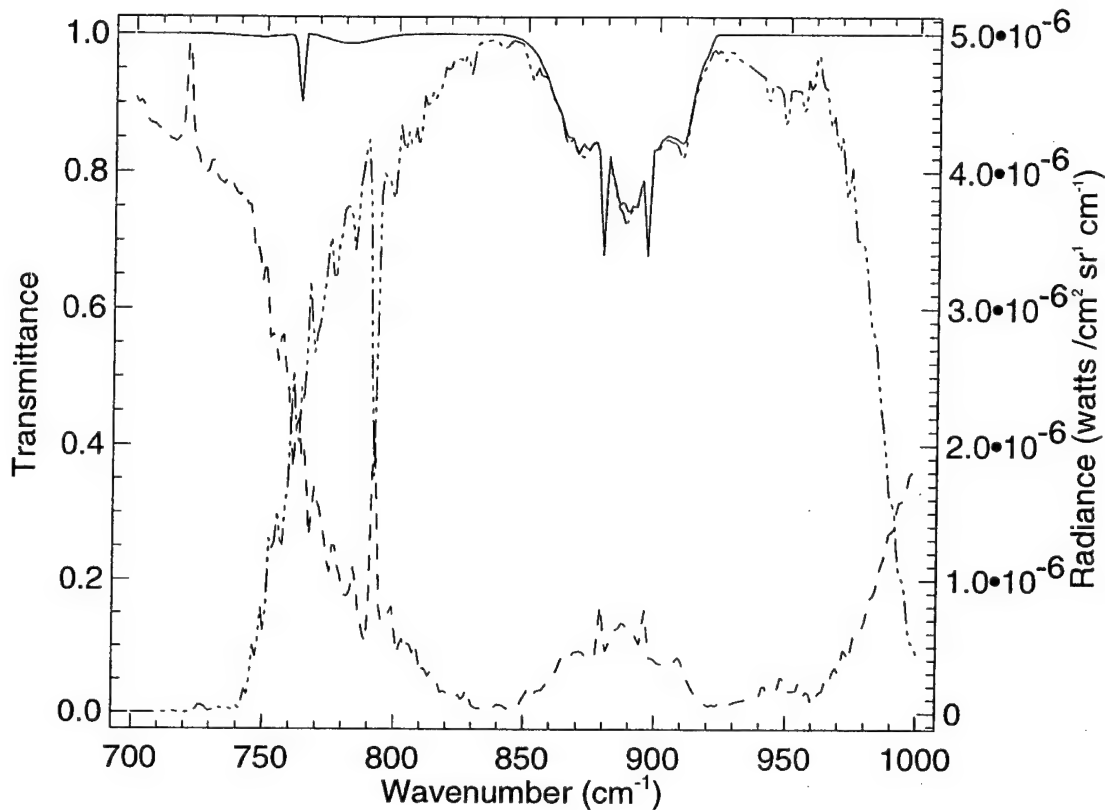


Figure 1. Modtran Calculation Showing HNO_3 in the Ambient Atmosphere Between 700 and 900 cm^{-1} for a Limb Path with a Tangent Height of 10 km. The solid line is the transmittance of HNO_3 alone, the dashed-dotted line is the total transmittance, and the dashed line is the radiance.

A rough sensitivity calculation with MODTRAN shows that at the most sensitive frequency in the band the change in transmittance δT is related to the change in the integrated absorber amount δu by:

$$\delta T = 0.5 \delta u / u \quad 6$$

For a 10 km tangent height limb path and the US Standard Atmosphere, $u = 1.26 \times 10^{-2} \text{ atm-cm} = 3.8 \times 10^{-5} \text{ gm cm}^{-2}$. If we require that $\delta T = 0.10$ then the required change in the column amount is $\delta u = u \delta T / 0.5 = 7.4 \times 10^{-5} \text{ gm cm}^{-2}$. Note that most of the absorber for a limb path is concentrated in a layer near the tangent point. Now MSX had a FOV at the tangent height of 4 by 13 km for a cross-sectional area A of $5.2 \times 10^{11} \text{ cm}^2$. If we assume that the LOS is roughly a rectangular cylinder with this cross-section, then the total mass m required is:

$$m = A \times u \quad 7$$

Substituting for A and u gives $m = 20 \times 10^3 \text{ gm}$ or 20 metric tons.

Note that this 20 tons of HNO_3 is only the amount contained within the FOV. Clearly the gas that diffuses up from the ground to 10 km would be spread over a much wider horizontal area so that orders of magnitude more HNO_3 would have to reach 10 km altitude. Intuitively, the magnitude of a ground source required to put this much HNO_3 into the atmosphere would greatly exceed any reasonable scenario.

Our conclusion is then that it is not possible for MSX to detect a ground release of fuming nitric acid by measuring the enhanced signal of HNO_3 in the limb.

5. Conclusions and Recommendations

The nadir view scenario requires a minimum detectable concentration of 4000 metric tons of NO_2 , based on a rough calculation. However, changes in the instrument specifications and refinements in the calculation might reduce this amount to a more reasonable level. We propose that a more refined calculation be performed.

The limb viewing scenario would require an unreasonably large release of nitric acid at the ground to provide a detectable signal for a 10 km tangent height.

Appendix B: SBVISI: Automated Processing Software For the UVISI and SBV Data at the Earthlimb DAC

SBVISI: Automated Processing Software For the
UVISI and SBV Data at the Earthlimb DAC

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-DRAFT-
August 4, 1994

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1. Introduction

2. Products

The products of the SBVISI Earthlimb Automated Processing are files containing:

- images, reformatted and tagged with identifying geolocation information, and
- vertical profiles of the radiance extracted from the images, plus cumulative statistics.

2.1 Image Files

2.1.1 Image File Names

The UVISI Level 2 file names, from which these Level 3 image files are derived, have the form^{1,2}:

`UJ_eventid_ii_oofft.L2_n`

where:

eventid = Event ID
ii = number of times this file has been sent for this event
oo = observation number as defined by MPC
ff = file number as defined by MPC
t = spacecraft tape recorder designation of A or B
n = 1-4 for IUW, IUN, IVW and IVN respectively

Level 3 image files are created for all four imagers: IUW, IUN, IVW and IVN. The name of each Level 3 image file is the name of the Level 2 UVISI file with ".image" appended to it, for example:

`UJ_EL02CP0000200_01_0101A.L2_3.image.`

These files are stored in the directory specified in the processing script file `processing_script.` as described in section 3.3.

The SBV Level 2 file names are of the form³:

`yydddhhmmsss_00ff.DAT`

where:

yy = last two digits of year of the first frame of data for this DCE (not for this frameset)
ddd = day number in the year starting from 1 January (= day 1)
hh = universal time hours
mm = universal time minutes
sss = universal time in tenths of seconds

¹ MSX Missions Operations Center Data Products, JHU/APL publication SDO 9861, February, 1996

² Eichert, J. J., J. F. Carbary, L. L. Suther, UVISI Data Processing Center Convert User's Manual, Version 2.0, JHU/APL publication SDO 10148.5, May, 1995

³ Opar, T. P., SBV Convert v2.0 User Guide (Draft), MIT/LL, 1996

ff = frameset number

The level 2 files for a DCE are organized into "framesets". A frameset is a collection of consecutive images all recorded with the same four parameters: CCD number, exposure time, gain state, and zero correction. Whenever one of these parameters is changed, SBV Convert generates a new Level 2 file corresponding to a new frameset. Currently, all the Earthlimb experiments hold these parameters constant throughout the whole DCE. There is also a limit to the number of images contained within a single frameset. This number is a parameter within SBV Convert: for SBV Convert run at the PL DAC, this number is set to 1024. Since SBV outputs 1 image every 13 seconds at the 5 MBts rate and 1 image per sec at the 25 MBts rate, all the images for single 5 MBts experiment can be contained within a single frameset, while at most two framesets are needed for a 25 MBts experiment.

The name of each SBV Level 3 image file is the Level 2 filename with ".image" appended to it, for example:

962051354135_0001.DAT.image

For the Level 3 image file, all the images for a single DCE are included in a single file. Therefore, the frameset number *ff* in the Level 3 file name will always be 1 even if there is more than one Level 2 frameset.

2.1.2 Image File Format

The format of the image files for both UVISI and SBV is sketched in Figure 1. In each case, the Level 2 file header (UVISI: the BDC file header, SBV: the Look Number Index) is copied over directly. The next position contains a long integer giving the number of images to follow. Each image is preceded by a Level 3 image header, as defined in Table 1, and the instrument image header (UVISI: the UVISI image header⁴, SBV: the Frame Number Index³) copied unchanged from the corresponding Level 2 file. The image can be of the type byte, short or long integer, or float, as specified by the appropriate field in the Level 3 image header. The image array is reordered from the way it appears on the Level 2 files. For both UVISI and SBV, the image is written by rows, starting with the lower left hand corner of the image

For the UVISI data at the low data-rate (5 MBts), each image from the Level 2 file is copied to the Level 3 file. For the high data-rate DCE's (25 MBts), only every forth image is copied, reducing considerably the size of the resulting file but preserving significant overlap between successive images. All SBV images are included in the Level 3 file.

⁴ Suther, L. L., J. J. Eichert, J. F. Carbary, UVISI Data Processing Center Interface Control Document with Naval Research Laboratory Backgrounds Data Center, JHU/APL publication SDO 9973.7, May, 1995

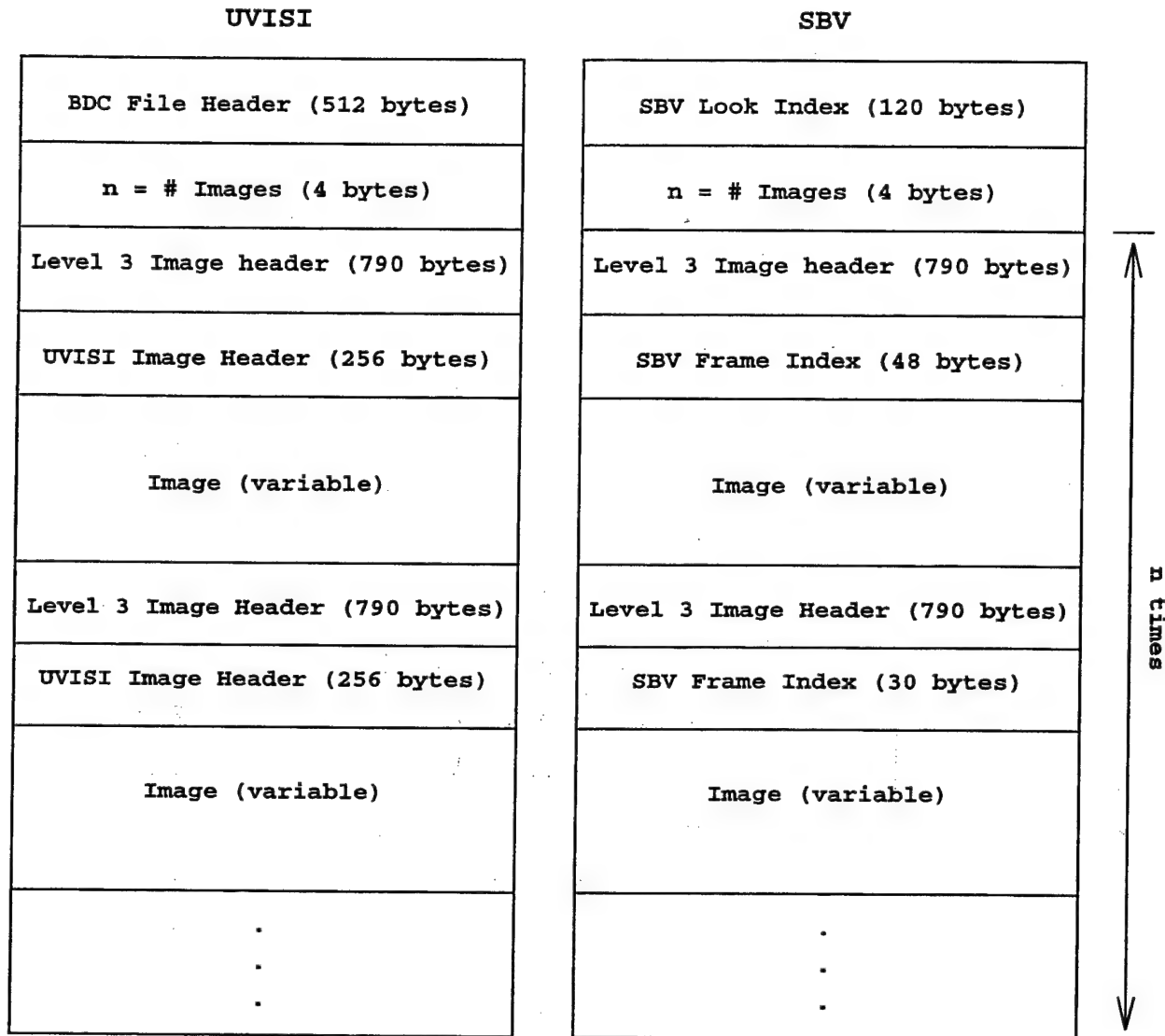


Figure 1. Structure of the Image Files

Table 1. Format of the Structure **Image_header**

Bytes	Description	Units	Type	Range
1-2	Instrument :	-	I*2	UVISI = 1 SBV = 2
3-4	Imager:	-	I*2	UVISI: 1-4 SBV (ccd): 1-4
5-6	Filter: UVISI only	-	I*2	1-6
7-14	Time at beginning of image	-	MSX_time (1)	
15-16	Image depth	bits	I*2	4, 8, 16, 32
17-18	Pixels in x direction	pixels	I*2	UVISI: 122 or 244 SBV: 420
19-20	Pixels in y direction	pixels	I*2	UVISI: 256 SBV: 420, 357 or 177
21-24	Gain state	-	R*4	UVISI: 0-93 SBV: 1 or 2
25-28	Exposure (sec)	sec	R*4	UVISI: 0-211 SBV: .4, 1, 1.6
29-32	Zsum (SBV only)	?	R*4	UVISI: (na) SBV:
33-36	Offset	(var)	R*4	
37-40	Multiplier: Radiance = image*Multiplier + Offset		R*4	
41-42	Radiance Units		I*2	0: counts 1: radiance 2: irradiance
43-46	Min. Radiance		R*4	
47-50	Max. Radiance		R*4	
51-150	Reference point pointing (bottom center pixel)		Reference (1)	
151-750	Registration Pointing: x, y indices, tangent height and nadir angle for 25 points around the image		Registration (1)	
751-790	Spare		10 x R*4	

Notes:

1. These structures are defined in later tables.
2. In the Column **Type**, B = byte, I = integer, R = real

The structure of the image headers and the profile headers depend upon the data structures shown in Tables 2 through 4. **MSX_time** (Table 2) is the standard MSX time as defined in the MOC Data Products¹. **Reference** (Table 3) specifies a set of pointing parameters for a reference LOS for an image or a profile. The x and y pixel indices (indices start

at 0, not 1) specify the reference pixel at the bottom middle of the image: the parameters following refer to the LOS through this pixel. Right ascension and declination specify the LOS in ECI J2000 coordinates. The remaining parameters all refer to the tangent point/pierce point, except for nadir angle, which is at the spacecraft.

The structure **Registration** (Table 4) gives the tangent height and nadir angle (at the spacecraft) for a 25 point grid overlaying the image. This grid is shown in Figure 2 and is designed to allow the tangent height and nadir angle for any other point on the image to be obtained by interpolation. The tangent height and nadir angle vary non-linearly across the image due both to distortion in the imagers and to non-linearities in the tangent height across the FOV. Point 3 is the Reference point in the previous paragraph. Although not visible in this figure, the registration points may actually be indented a few rows or columns inside the image. Indenting is done to ensure that the registration points are evenly spaced and because the distortion is greatest near the edges of the images.

Table 2. Format of the Structure **MSX_time**

Bytes	Description	Units	Type	Range
1	Year: 1-99	years	B	0 to 99
2-3	Day: 1 -366	days	I*2	1 to 366
4	Hour: 0-23	hours	B	0 to 23
5	Minute: 0-59	min	B	0 to 59
6	Second: 0-59	sec	B	0 to 59
7-8	Millisecond: 0-999	msec	I*2	0 to 999

Table 3. Format of the Structure **Reference**

Bytes	Description	Units	Type	Range
1-4	Index of x pixel		I*4	UVISI: 122 or 60 SBV: 210
5-8	Index of y pixel		I*4	UVISI: 1 SBV: 2, 0 or 0
9-12	Right Ascension	deg	R*4	
13-16	Declination	deg	R*4	
17-20	Nadir angle at spacecraft	deg	R*4	0 - ~80
21-24	Roll angle of spacecraft about the horizon	deg	R*4	0 - 180
25-28	Tangent height	km	R*4	0 to 800: -99 if > 800 -1 if ≤ 0
29-32	Nadir angle at the pierce point	deg	R*4	0 to 90
33-36	LOS azimuth	deg	R*4	0 to 360
37-40	Latitude	deg	R*4	-90 to 90
41-44	Longitude	deg	R*4	-180 to 180
45-48	Solar zenith angle	deg	R*4	0 to ~90
49-52	Solar azimuth angle	deg	R*4	0 to 360
53-56	Lunar zenith angle	deg	R*4	0 to ~90
57-60	Lunar azimuth angle	deg	R*4	0 to 360
61-100	Spare		R*4	

Note: As of this writing, the Nadir angle at the spacecraft and the Roll angle have not been implemented in the pointing software. These parameters are set to Not-A-Number.

Table 4. Format of the Structure **Registration**

Bytes	Description	Units	Type	Range
1-50	Index of x pixels		25 x I*2	
51-100	Index of y pixels		25 x I*2	
101-200	Tangent Heights	km	25 x R*4	0-800: -99 if > 800 -1 if ≤ 0
201-300	Nadir Angles (at spacecraft)	deg	25 x R*4	0 - ~80
301-400	Right Ascension	deg	25 x R*4	
401-500	Declination	deg	25 x R*4	
501-600	Spare		25 x R*4	

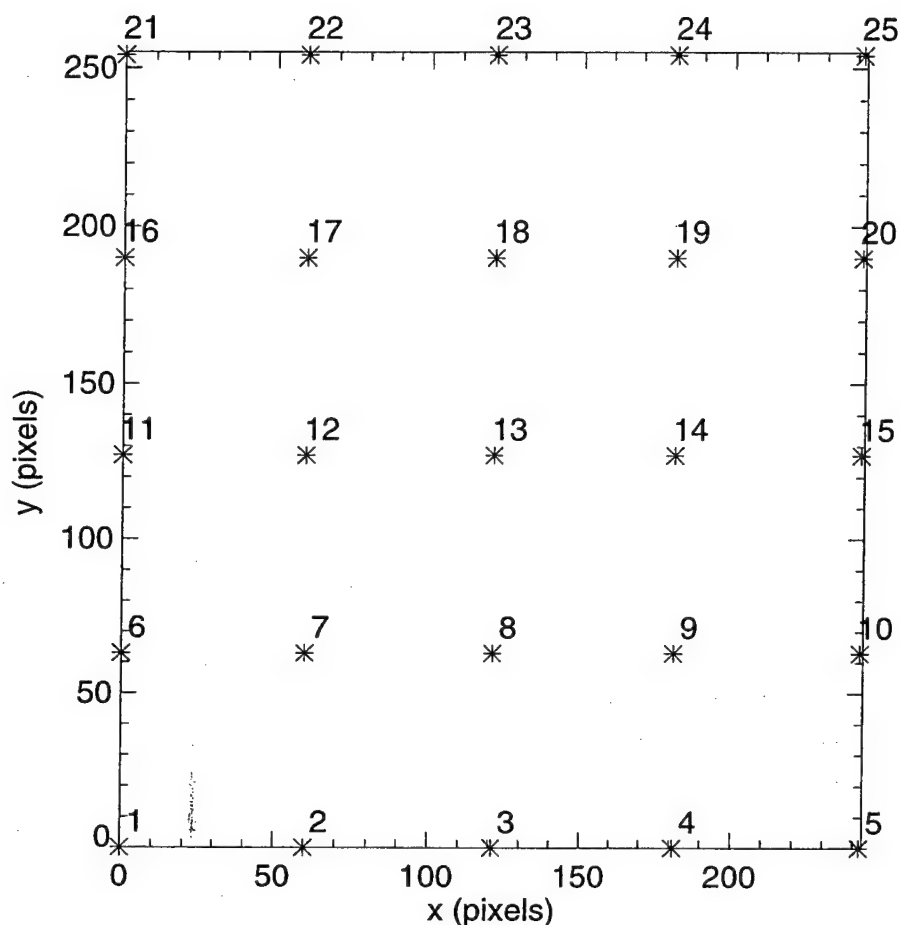


Figure 2. Image Registration Points, UVISI Image

2.2 Profile Files

Two types of radiance profiles are produced: pixel and binned. The pixel profiles contain the individual pixel values for a vertical slice through an image while the binned profiles contain the radiance averaged vertically over 1 km thick bins. (The radiance values are also averaged horizontally: see Section 4.1.2 for a discussion of this averaging.) Two profiles of each type are extracted from each image: these profiles are designed to correspond spatially (in the horizontal direction) to the two detector columns ADE and BC of the SPIRIT III radiometer. Profiles are extracted only from the narrow imager. For UVISI, profiles are extracted from each narrow image at both the 5 and 25 MBts data rates (only every fourth image is stored at the 25 MBts data rate.) Profiles are extracted from all SBV images.

The locations of the two vertical profiles relative to the UVISI and SPIRIT III images are sketched in Figure 4. On the SPIRIT III radiometer, the detector columns B and C are separated from the columns A, D and E by 0.251 deg. Therefore, simultaneous images for bands A, D and E

will be offset by this amount compared to those for B and C, as will the radiance profiles derived from these images. In an attempt to match the spatial locations of the radiometer profiles, radiance profiles are extracted from the UVISI and SBV images in the locations shown in Figure 3.

2.2.1 Profile File Names

The Level 3 profile file names are the Level 2 file names appended with ".pixel" and ".binned" for the pixel and binned profiles respectively. The location of these files is specified in the processing script.

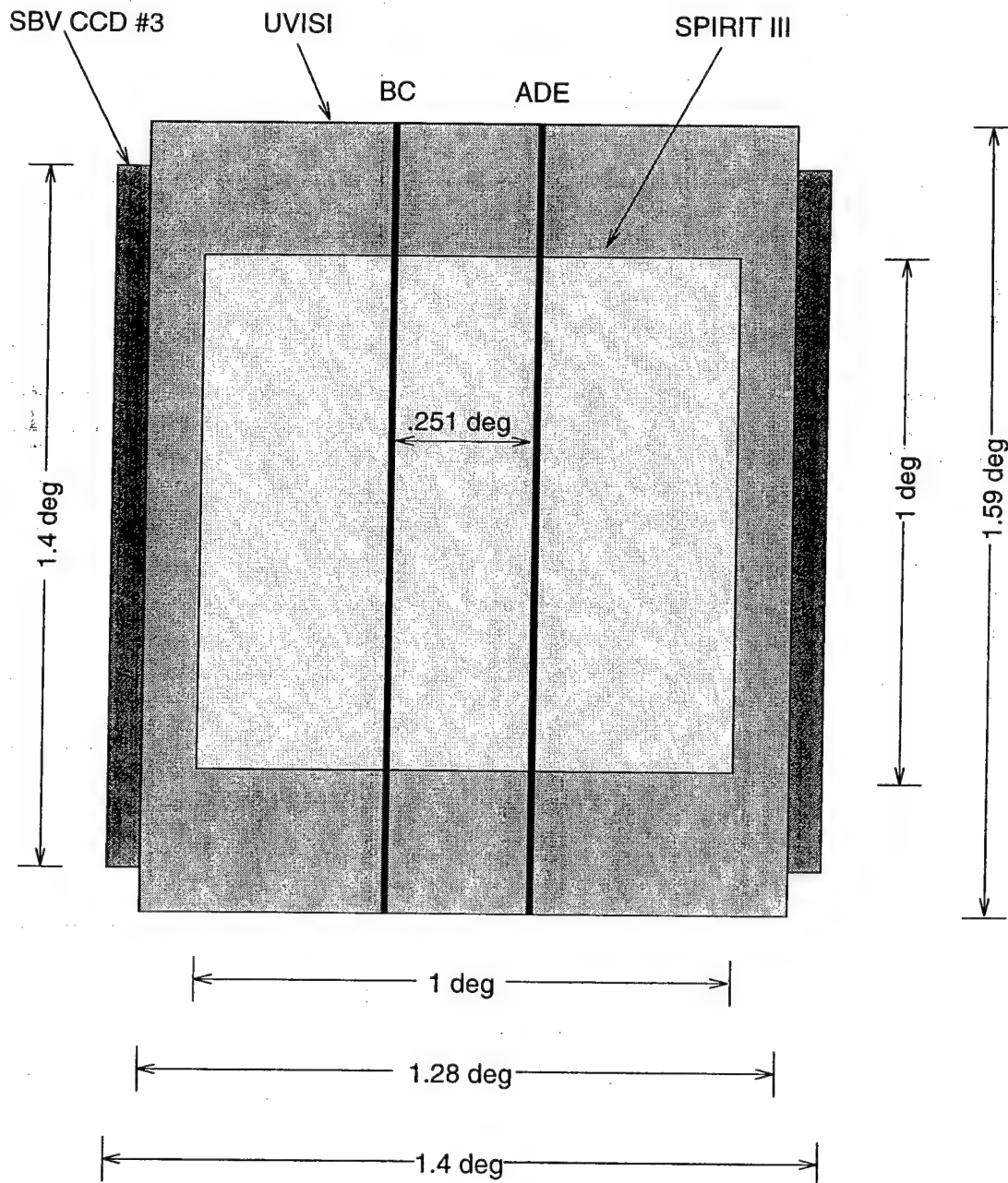


Figure 3. Sketch of Simultaneous UVISI Narrow, SBV and SPIRIT III Radiometer Image FOV's Plus the Relative Locations of the Radiometer Columns BC and ADE.

2.2.2 Profile File Format

The structures of the two types of radiance profile files--pixel and binned--are sketched in Figure 4. As with the Level 3 image files, the profile files include the instrument file header (UVISI: BDC Header, SBV: Look Number Index) from the corresponding Level 2 image file. The next word contains the number of profiles to follow. The next word contains, for the binned profile file, the byte position in the file (starting from 0) of the beginning of the Profile Statistics. For the pixel profile, there is no Profile Statistics and this word is 0. The structure of the profile header is defined in Table 5 while the structures of the pixel profiles and the binned profiles are defined in Tables 6 and 7 respectively. Finally, the binned profile file contains a statistical summary of the profiles. For each altitude bin with three or more samples, the summary contains the number of samples and the mean, minimum, maximum and standard deviation of radiance. The format of the statistical summary is defined in Table 8.

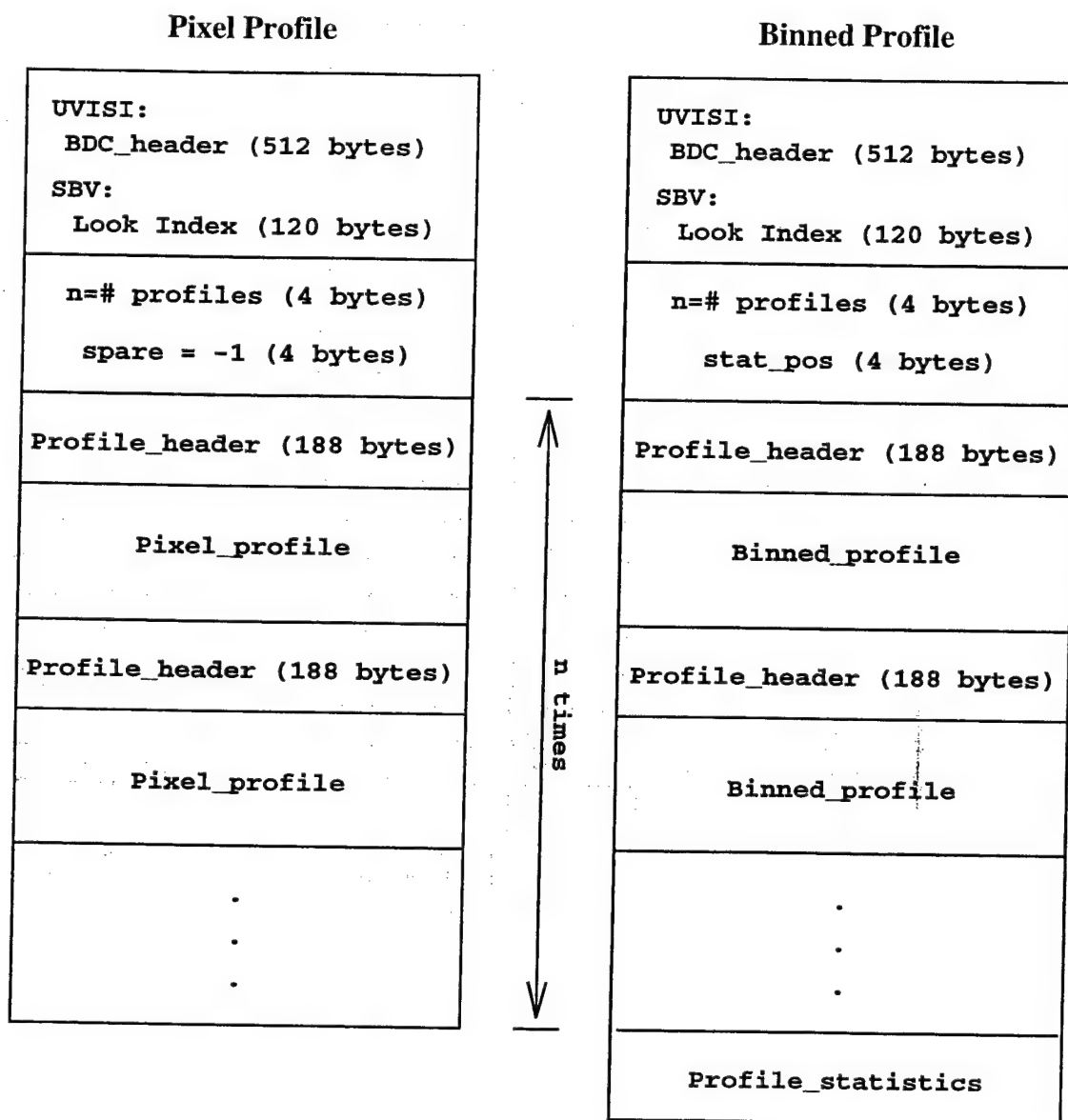


Figure 4. Structure of the Pixel and the Binned Profile Files

Table 5. Format of the Structure **Profile_header**

Bytes	Description	Units	Type	Range
1-8	Time of corresponding image	-	MSX_time	
9-10	Instrument	-	I*2	UVISI = 1 SBV = 2
11-12	Imager	-	I*2	UVISI: 1-4 SBV (ccd): 1-4
13-14	Filter wheel position (UVISI only)	-	I*2	UVISI: 1-6 SBV: 0
15-16	Grid type: altitude or nadir angle	-	I*2	0 = altitude 1 = nadir angle
17-116	Reference pointing for corresponding image	-	Reference	
117-132	Vertical grid for first (binned) profile (BC)	-	z_grid	
133-148	Vertical grid for second (binned) profile (ADE)	-	z_grid	
148-188	Spare		10 x R*4	

Note: Pixel profiles are not on a regular grid. For these profiles, **z_grid** contains the minimum and maximum altitude, and the number of points **z_grid.dz = -1**.

Table 6. Format of the Structure **Pixel_profile**.

Bytes	Description	Units	Type	Range
0 - n_1-1	Tangent height, columns BC	km	$n_1 \times R*4$	0 to 800: -99 if > 800 -1 if ≤ 0
n_1-1 - n_1+n_2-1	Tangent height, columns ADE		$n_2 \times R*4$	
n_1+n_2 - $2n_1+n_2-1$	Nadir angle, columns BC	deg	$n_1 \times R*4$	0 - 80 -99 if > 80
$2n_1+n_2$ - $2n_1+2n_2-1$	Nadir angle, columns ADE		$n_2 \times R*4$	
$2n_1+2n_2$ - $3n_1+2n_2-1$	Radiance profile, columns BC	watts $\text{cm}^{-2} \text{sr}^{-1}$	$n_1 \times R*4$	
$3n_1+2n_2$ - $3n_1+3n_2-1$	Radiance profile, columns ADE		$n_2 \times R*4$	

Notes:

1. $n_1 = \mathbf{z_grid.n}$ (BC), $n_2 = \mathbf{z_grid.n}$ (ADE), where **z_grid.n** is from the Pixel Profile Header (actually n_1 and n_2 will be the same.)
2. UVISI: **z_grid.n** = 253
3. SBV: **z_grid.n** = 417, 357, or 177

Table 7. Format of the Structure **Binned_profile**.

Bytes	Description	Units	Type
0 - n_1-1	Radiance profile, columns BC	watts cm ⁻² sr ⁻¹	$n_1 * R * 4$
$n_1 - n_1+n_2-1$	Radiance profile, columns ADE	watts cm ⁻² sr ⁻¹	$n_2 * R * 4$

Notes:

1. $n_1 = \mathbf{z_grid.n}$ (BC), $n_2 = \mathbf{z_grid.n}$ (ADE), where $\mathbf{z_grid.n}$ is from the Binned Profile Header
2. n_1 and n_2 need not be the same and may each vary from profile to profile.
3. Profiles may be binned on either tangent height or nadir angle, as specified in the Binned Profile Header

Table 8. Format of the Structure **Profile_statistics**.

Bytes	Description	Units	Type
0 - 15	Vertical grid for statistics	z_grid	
16 - 16+8*n-1	Number of samples per altitude bin		$2 * n * I * 4$
16+8*n - 16+16*n-1	Profile of minimum radiance	watts cm ⁻² sr ⁻¹	$2 * n * R * 4$
16+16*n - 16+20*n-1	Profile of maximum radiance	watts cm ⁻² sr ⁻¹	$n * R * 4$
16+20*n - 16+24*n-1	Profile of mean radiance	watts cm ⁻² sr ⁻¹	$n * R * 4$
16+24*n - 16+28*n-1	Profile of standard deviation	watts cm ⁻² sr ⁻¹	$n * R * 4$

Notes:

1. $n = \mathbf{z_grid.n}$
2. The grids for the profiles for columns BC and ADE are the same, however, some bins at the top and the bottom of the grid may be unpopulated. In this case, samples = 0 and the profile values = -99.
3. For bins where the number of samples per bin is 0, the corresponding value of the minimum, maximum, mean, and standard deviation is the IEEE Not-a-Number (NaN)

Table 9. Format of the Structure **z_grid**

Bytes	Description	Units	Type	Range
1-4	Initial altitude or nadir angle: Z_1	km or deg	R*4	altitude: 0 to 800 angle: 0 to ~80
5-8	Final altitude or nadir angle: Z_2	km or deg	R*4	altitude: 0 to 800 angle: 0 to ~80
9-12	Altitude or angle increment: dZ	km or deg	R*4	altitude: nominal = 1 angle: nominal = 0.02
13-16	Number of levels: $N = (Z_2 - Z_1)/dZ + 1$		I*4	

2.2.3 Log File

3. Program Usage

The SBVISI automated analysis software is written in the Interactive Data Language (IDL) by Research Systems, Inc., Boulder Colorado. IDL is an interpretive language and does not need to be compiled before running. IDL program, procedure and function files all have the extension `.pro`.

IDL is available on all the following hardware platforms at the PLDAC: Sun SparcStation, HP, and SGI. However, the pointing software MAMBA, which is written in Fortran, is currently only configured to run on a Sun SparcStation. See Section 3.4 on the steps necessary to configure MAMBA to run on another platform.

The rest of this section describes how to install the software from the distribution file, configure the pointing software MAMBA, prepare the processing scripts, and run the programs

3.1 Installing the Software

The SBVISI Automate Analysis software package is distributed as a Unix tar file compressed with gzip. The file name is:

```
SBVISI_auto_analysis_vv.r.tar.gz
```

where *v* is the version number and *r* is the revision number. To extract the package, place this file in an empty directory, for example `SBVISI_auto_analysis`, and enter the commands:

```
gunzip SBVISI_auto_analysis_vv.r.tar.gz
```

```
tar -xvf SBVISI_auto_analysis_vv.r.tar
```

The files will then all be extracted and placed in the proper directories. Figure 5 shows the resulting directory tree. The different directories contain:

<code>doc</code>	program documentation in postscript file format (including this report)
<code>idl_auto_analysis</code>	IDL source code for the automated analysis software (see Section 4.x for a directory listing)
<code>idl_utilities</code>	IDL source code for the Level 3 file viewers and other general utility programs
<code>mamba</code>	PLDAC pointing software library, interface software and data files
<code>sbv</code>	directories for the SBV Level 3 products (images and profiles) and log files, as specified in the sample SBV processing script plus a directory of SBV-specific IDL utility programs
<code>uvisi</code>	as <code>sbv</code> but for UVISI

The directories `images`, `log`, and `profiles` under `sbv` and `uvisi` are initially empty and may not be needed depending on the paths specified in the processing script files.

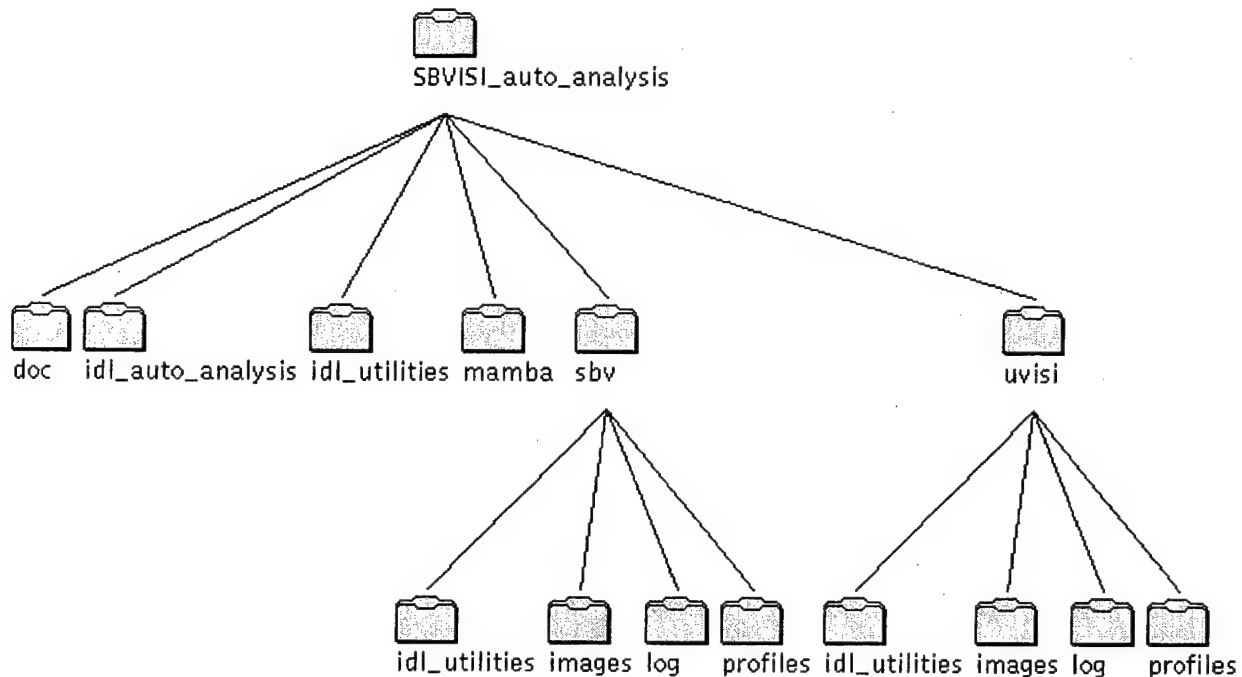


Figure 5. Directory Tree Structure of the SBVISI Automated Analysis Software

The following files are found in the root directory (here `SBVISI_auto_analysis`):

`README`

Program updates and corrections produced too late for inclusion in this report

`refrvars.dat@`

a [link](#) the file `refrvars.dat`, used by the pointing software MAMBA and required to be in this directory

`run_auto_analysis`

an IDL command file to run the automatic analysis

`sbv_processing_script`

processing options, file paths and names for SBV

`uvisi_processing_script`

processing options, file paths and names for UVISI

3.2 Interfacing with the Pointing Software "Mamba"

The PLDAC geolocation software MAMBA is used to calculate various geocentric parameters such as tangent height, nadir angle, and latitude and longitude at the tangent/pierce point. This software is written in Fortran and is provided by the PLDAC as a object library `mambalib_so.o`. The Fortran subroutines `call_mamba.f` and `uvisi_mamba.f` provide an interface between the mamba routines and IDL. However, IDL requires that these external routines be provided in the form of a shared object. The makefile `Makefile` is provided to compile the Fortran subroutines and to link them, the MAMBA object library, and the needed system libraries into the necessary shared object. In order to make the shared object, simply go to the mamba subdirectory and enter the command: `make`.

Note however that the MAMBA object library is provided as a Sun Sparc relocatable binary library file. If the SBVISI Automated Analysis Software is to be run on a platform other than a Sun SparcStation, then the MAMBA software must be compiled on that platform. The makefile will have to be modified to load the necessary system libraries. Finally, the call to `call_mamba` in the procedure `get_pointing.pro` will have to be modified as appropriate to the target platform. (See Chapter 18 of the IDL User's Guide⁵.)

(NaN issues: Sun vs. HP)

3.3 Processing Scripts

The program operation and options are controlled by separate script files for UVISI and SBV named `uvisi_processing_script` and `sbv_processing_script`, located in the directory from which the program is run. Table 10 describes the contents of these files while Table 11 shows a sample processing script file for SBV.

The specific lines should specify as follows: line 1 gives the base file name for the Level 2 data for the desired DCE, as specified in Section 2.1.1. The base file name is the Level 2 file name without:

UIVSI: the extension `.L2_n`

SBV: the extension `_00ff.DAT`

Line 2 specifies the full name of the definitive attitude file. Line 3 specifies the path name for the SBVISI log file (see section 2.2.3). Line 4 gives the path to the Level 2 image files while line 5 gives the path name for the definitive attitude file for this DCE. Line 6 gives the path name for the sensor alignment and distortion files which are provided with the UVISI and SBV convert programs (see section 4.7 for a discussion of these files): these files should be found in the appropriate convert directories. Lines 7 and 8 specify the paths for the output Level 3 profile and image files. Finally, line 9 specifies the only processing option: whether the binned profiles should be binned on tangent height or nadir angle.

⁵ RSI, 1995, IDL User's Guide, Research Systems, Inc., Boulder, Colorado

Table 10. Processing Script File Contents

Line	Parameter	Example
1	Level 2 file base name	UVISI: UJ_EL02CP0000101_01_0101A SBV: 951501732180
2	Definitive Attitude file name	UJ_EL02CP0000101_01_0101A.25A
3	Processing log file path	/data/sbv/test_data/log/
4	Level 2 data file path	/data/sbv/test_data/
5	Definitive attitude Path	/data/attitude/test_attitude/
6	Path to sensor alignment and distortion files	/convert/sbv/
7	Level 3 profile file path	/data/sbv/test_data/profiles/
8	Level 3 image file path	/data/sbv/test_data/images/
9	Processing option: 1: bin on tangent height 2: bin on nadir angle	1

Table 11. Sample SBV Processing Script File

```

951501732180          ;SBV Level 2 file base name
UJ_EL02CP0000101_01_0101A.25A ;Attitude file name
/data/sbv/test_data/log/      ;Processing log file path
/data/sbv/test_data/         ;Level 2 data file path
/data/attitude/test_data/     ;Definitive attitude path
/convert/sbv/;              ;Path to sensor alignment and distortion files
/data/sbv/test_data/profiles/ ;Output profile file path
/data/sbv/test_data/images/   ;Output image file path
1                             ;1=grid on tangent height, 2 on nadir angle
-----This line and below is ignored-----

```

In reading the processing script, the program reads each line up to the end or to a semicolon and strips off any trailing blanks before returning the character string. In this way, comments can be added to any line. Any lines after line 8 are also ignored and comments can be added here also.

In specifying path names, it is safest to provide the absolute path name: relative path names may not work under some circumstances. Specifically, the "~" (tilde) character starting a relative path name may fail to work properly in some environments.

3.4 Running the Program

To run the SBVISI Automated Analysis Program, the working directory must be set to the root of where the software was installed. The IDL environments variable must be set as follows:

IDL_DIR /appl/idl

IDL_PATH +/appl/idl

The program is then run by entering the command:

idl run_auto_analysis

This command starts up idl and instructs it to execute the batch command file run_auto_analysis which is found in the working directory. The contents of this file is listed in Table 12

Table 12. Batch Command File run_auto_analysis

```
;Note: anything following a semicolon (;) is a comment

;The following command ensures that idl can find all the necessary procedures
!path=expand_path('+. /idl_auto_analysis:+. /idl_utilities')+':'+!path

.rnew auto_analysis_uvisi        ;run the program auto_analysis_uvisi
.rnew auto_analysis_sbv        ;run the program auto_analysis_sbv

exit                            ;exit idl
```

The first command sets the IDL system variable !path so that IDL can find all the necessary functions and procedures, both system and specific to the SBVISI Automated Analysis. The next two commands run the IDL programs auto_analysis_uvisi.pro and auto_analysis_sbv.pro, which are found in the directory ./idl_auto_analysis. These two files are separate idl main programs which process the UVISI and SBV data respectively. (If desired, these programs can be run independently.) The last command simply exits idl and returns to the command prompt.

3.5 Error Conditions and Trapping

4. Program Descriptions

4.1 Automated Analysis Program

4.2 Level 3 File Viewers

Appendix C.

General Inversion Package for Advanced Retrieval of Atmospheric Species from High Spectral Resolution Measurements

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A general inversion algorithm based on the Rodgers (1976, 1990) optimal inversion approach is being developed. The algorithm is applicable to the simultaneous retrieval of any ensemble of selected molecular species as well as atmospheric temperature from down-looking, up-looking or limb measurements. The algorithm has been designed to use FFASCODE for the molecular optical depths calculations but can be modified to run with faster transmittance models (e.g. MODTRAN). Substantial computational gain is achieved over the existing "Path Characterization algorithm (Isaacs et al 1990), by performing the K-matrix calculation analytically and by making the code fully vectorizable. The algorithm has been applied successfully to the simultaneous retrieval of temperature and water vapor from the ground based interferometric measurements (Theriault et al. 1993) The algorithm will be applied to CIRRIS data and to MSX data when available.

Appendix D. FASCODE Environment (FASE)

A poster paper presented at the Annual Review Conference on Transmission Models, Phillips Laboratory, Hanscom AFB, MA June 7-8, 1994

FAScode for the Environment: *FASE*

J. L. Moncet and William Gallery
AER, Inc.

Gail Anderson
Phillips Lab/Optical Physics Division

Goals

- On-going Development of FASCODE
- State-of-the-Art Line-by-line Atmospheric Radiation Model
- Satisfy Needs of:
 - Current users--defense community
 - Emerging environmental applications
- Incorporate Best Physics and Software Engineering

Physics:

- Include Latest Advances from ARM
- Continua: Latest Available or User Supplied
- Simultaneous Radiance and Derivatives for Inversions
- Improved Cross-Section Models
- Voigt Shape Used Throughout
- Spectral Scanning Using FFT's

Software:

- Improved User Interface
- Modern Coding Techniques: e.g. Include Files for Common Blocks
- Improved Numeric Accuracy
- Vectorization for Parallel Processing
- Improved Documentation, Including Interfaces

Packaging

- All Independent Modules
 - Atmosphere, Optical Depth, Radiative Transfer, Filtering, Scanning, Plotting
 - Run Together Through Scripts (Batch Files) or Drivers
- Makefiles: Unix, VMS, MS-DOS
- Distribution by tar or zip File
- Under Configuration Control: SCCS

New Applications

- Training Fast Parameterizations
- Cooling Rates
- Inversion
- Multiple Scattering Through Interface with External Code

